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Large-scale carbon sequestration in post-agrogenic ecosystems in Russia and Kazakhstan

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ABSTRACT

Most land use changes (LUC) significantly affect the amount of carbon (C) sequestered in vegetation and soil, thereby, shifting the C balance in ecosystems. Disintegration of the USSR and the followed collapse of collective farming system have led to abandonment of more than 58 million ha (Mha) of former croplands in Russia and Kazakhstan that comprise together about 90% of land area in the former USSR. This was the most widespread and abrupt LUC in the 20th century in the northern hemisphere. The spontaneous withdrawal of croplands in 1990s caused several benefits for environment including substantial C sequestration in post-agrogenic ecosystems. The new estimations of net ecosystem production (NEP) and changes in soil organic carbon stocks (ΔSOC) in post-agrogenic ecosystems presented here are based on the uniform bio-climatic approach, and hereby, allow to update C balance of the former USSR. The total extra C sink in abandoned croplands in Russia (45.5 Mha) and Kazakhstan (12.9 Mha) is estimated to be 155 ± 27 Mt C yr^{-1} and 31 ± 2 Mt C yr^{-1}, respectively. This additional C sink could cover about 18% of the global CO_2 release due to deforestation and other land use changes or compensate annually about 36% and 49% of the current fossil fuel emissions in Russia and Kazakhstan, respectively. The extra C sink to the post-agrogenic ecosystems in Russia and Kazakhstan contributes possibly about 1/3 part to the total current C balance of the former USSR. Hence, the disintegration of the former USSR significantly affected national and global C budget over few decades after LUC.

1. Introduction

Most land use changes (LUC) significantly affect the amount of carbon (C) sequestered in vegetation and soil, thereby, shifting the C balance in ecosystems (Houghton, 2010). The greatest C fluxes caused by LUC are attributed to conversion of croplands to native vegetation and vice versa (Houghton and Goodale, 2004; Schlesinger, 1986). A large number of reviews and experimental studies report that abandoned agricultural land (remaining without cultivation) will be occupied by natural vegetation, that lead to organic C accumulation both in soil (Guo and Gifford, 2002; Kalinina et al., 2011, 2013, 2015; Kurganova and Lopes de Gerenyu, 2008, 2009; Lyuri et al., 2010) and in vegetation (Kurganova et al., 2007, 2008; Pérez-Cruzado et al., 2011; Post and Kwon, 2000).

The magnitude of annual C sink in soil and vegetation varies widely and depends on the intensity of previous land use, soil type (or fertility), and climate (Johnson and Curtis, 2001; Kurganova et al., 2010b, 2014; Uhl et al., 1988). The rates of C accumulation in mineral soils are rather modest especially in comparison with much faster rates of C accumulation in vegetation, surface litter, or woody debris (Barford et al., 2001; Hooker and Compton, 2003; Kalinina et al., 2010). Based on global meta-analysis, Post and Kwon (2000) indicated that the average rate of C accumulation in soil is about 0.33 Mg C ha^{-1} yr^{-1} for grassland and forest establishment. According to IPCC report (2000), the conversion of arable land to grassland resulted in build-up of C stocks at rate of 0.5 Mg C ha^{-1} yr^{-1} over 50 years (range 0.3–0.8 Mg C ha^{-1} yr^{-1}). Soussana et al. (2004) estimated the average rate of C sequestration due to conversion of cropland to grassland to be 0.49 ± 0.26 Mg C ha^{-1} yr^{-1} for a 0–30 cm soil layer over first 20 years after LUC. In temperate climate, grassland establishment caused a long lasting C sink with average change of C stock of $39.8 \pm 11.0\%$ relatively to the initial level in the 30-cm topsoil over first 20 yrs. The afforestation on former croplands for the same period after LUC induced C sink of $22.4 \pm 10.4\%$ of initial level both in forest floor and in mineral soil (Poeplau et al., 2011). The C re-accumulation in soil usually lasts some decades and new equilibrium can be reached after 80–120 years (Poeplau et al., 2011; Soussana et al., 2004). Globally, C accumulation in mineral soils recovering from past tillage amounts for about 0.1 Pg C yr^{-1} (Post and Kwon, 2000).

Critical changes in land use caused by disintegration of the USSR, followed by economic crisis and abrupt shifts in agricultural policy, took place in the end of last century. The collapse of the Soviet farming system in early 1990s led to radical decrease of cropland area both in

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